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Breakdown Voltage Effect on coupling Ratio Fusion Fiber Coupling

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Abstract

The effect of breakdown voltage on coupling ratio of fiber coupler has been experimentally and theoretically studied. It has been calculated by developing pockel's effect. The experiment is done to investigate dc-voltage effect to the coupling ratio by designing fusion region of fabricated 1X2 SMF-28e® couplers between two dielectric plates. An optical power is launched to input port of fiber 1, and then the output powers are measured. The change of coupling ratio significantly depends on separation between two plates. By increasing dc-voltage from 10 Volt to 1000 Volt with separation between two plates is 2.5 mm, the coupling ratio increases from 0.48 to 0.525. This change is due to the breakdown voltage imposed the electric field corresponding to the refractive index of Silicon Dioxide.

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Keyword: Single mode fiber; breakdown voltage; coupling coefficient; and coupling ratio

1. INTRODUCTION

The development of optical fiber in network communication system has greatly expanded. It has been used to carry the data, video, voice and to require wide bandwidth and big capacity. The optical fiber network requires junctions to split the communication system. A fiber coupler is one of passive device having important role in optical circuit system. This component can be used in many applications such as splitting, combining, and switching optical signals [1] hence, it has interesting field to be studied. The optical directional fiber coupler was usually fabricated using fusion technique. Two single mode fiber (SMF-28e®) is twisted together, then both two sides is pulled during fusion. The mechanism is stopped when the pre-set value of coupling ratio is reached [2].

In optical application, some networking system needs to branch its signal from a device to another device with certain branch ratio (coupling ratio). In this case, the fiber coupler with tunable coupling ratio is required. In 2003, Analysis of directional coupler electro-optic switches using effective-index-based matrix method was reported. The optical directional coupler switch was made by the diffusion of Titanium in Lithium Niobate (Ti:LiNbO₃) substrates and incorporation of suitable electrodes [3]. In that study the normalized mode profile was shown at different propagating distance of a DC switch with uniform electrode. The Breakdown voltage investigation of fusion SiO₂

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optical coupler was also reported by using Pockel's effect model. The model is evaluated by using the coupling coefficient and the changes in the refractive index. When there is an applied voltage to the coupler, polarization of SiO₂ material occurred. All the positive elements will be attracted and arranged directed to the incident $E(x,t)$ [1, 4]. Here, it can be said that the incident electric field is much larger than the total electric field of the polarization phenomenon in the optical fiber.

The coupling ratio significantly depends on the refractive index change, the coupling coefficient, and the separation between the fibers [5]. In this paper, the breakdown voltage effect is experimentally purposed to provide fiber coupler by reducing refractive indices with tunable coupling ratio by applying dc voltage to the coupling region fiber coupling. The experimental result will be then compared to the theoretical calculation.

2. BREAKDOWN VOLTAGE EFFECT ON THE FIBER COUPLING.

When an external electric field is applied using suitable electrodes, the refractive index profile of the waveguides is modified due to electro-optic effect. This variation depends upon the type of electrodes used and on the relative position of the electrodes. There are two types of effect which relate to the variation of refractive index and the electric field applied. The Pockel's effect is known if the variation or refractive index linear to the applied electric field. In the other hand, Kerr effect is referred to if the variation in the refractive index is proportional to the square of the applied field. The refractive indices are the functions of the electrical field applied to materials. The refractive index change is considered linearly proportional to the applied electric field. One of common material used is Lithium Niobate. It is a widely used in electro-optic material due to the presence of the high electro-optic coefficient characteristic.

Consider the linear electro optic or Pockel's effect, the change of refractive index due to the applied voltage V is given as [3].

$$\Delta n(\lambda, y, V) = -\frac{n^3}{2} r E(x, y) \quad (1)$$

where E is the electric field applied from the parallel electrodes of voltage and perpendicular to the fiber. If the distance between the two electrodes are x , then E is given by this following equation.

$$E = \frac{V}{x} \quad (2)$$

The coupling coefficient of fusion fiber coupler is experimentally given as follows [6]

$$\kappa = \frac{\pi}{2} \frac{\sqrt{\delta}}{a} e^{[-A+B\delta+C\delta^2]} \quad (3)$$

where

$$\begin{aligned} A &= 5.2789 - (3.663V) + (0.3841V^2) \\ A &= -0.7769 - (1.2252V) + (0.0152V^2) \\ A &= -0.0175 - (0.0064V) + (0.0009V^2) \end{aligned} \quad (4)$$

and V is the normalized frequency.

$$V = \frac{2\pi a}{\lambda} \sqrt{n_1^2 - n_2^2} \quad (5)$$

The breakdown voltage effect is determined by substituting Pockel's equation to the empirical equation [3].

$$V_{DC} = \left[n_1 \left(2 - 2\sqrt{1 - \delta} - \delta \right)^{1/2} \right] \left[\frac{2x}{rn_1^3} \right] \quad (6)$$

It can be seen clearly from Equation (6) that the breakdown voltage much depends on the distance between two electrodes, and the refractive index of fiber coupler.

3. EXPERIMENTAL SET UP

The fabricated SMF-28e® coupler by setting the coupling ratio 40:60 is used to investigate the breakdown voltage on the coupling ratio. The input power P_0 , 1mW and wavelength 1550nm is launched to fiber 1. At the same time the dc voltage using a parallel electrodes is applied from 10-1000V. The electric field produced and the waves cross to the two fibers are only considered to the permittivity effect of silicon dioxide. The output power P_1 and P_2 are then measured by optical power meter. This schematic diagram of experimental set up can be depicted in Figure 1.

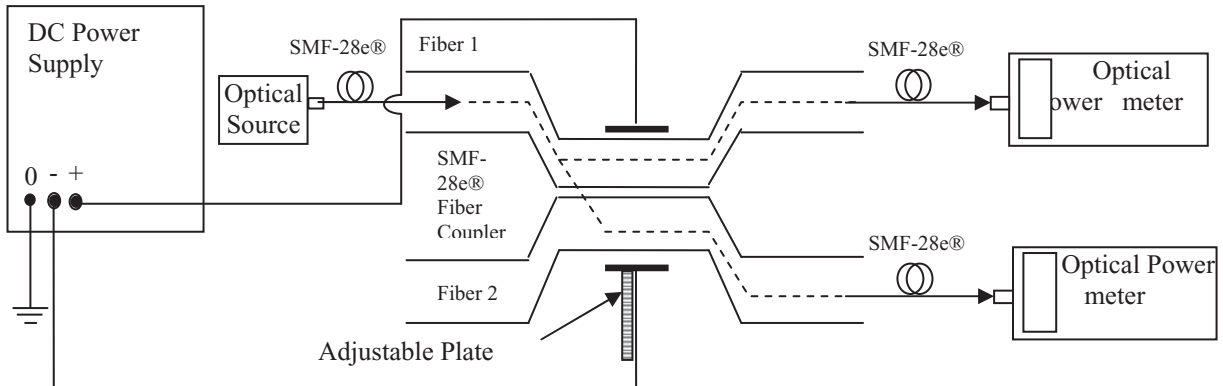


Figure 1. Breakdown voltage applied on the 1X2 fusion fiber coupler.

4. BREAKDOWN VOLTAGE: COMPARISON WITH CALCULATION

The change of coupling ratio by induced dc voltage to the coupling region of fusion fiber coupler has demonstrated. At first, the 1mW input power with wavelength 1550 nm is launched to the input port of fiber 1, and the voltage is set to zero. Both two output powers are measured with an assumption that the fiber coupler provides power lossless, and there is no insertion loss.

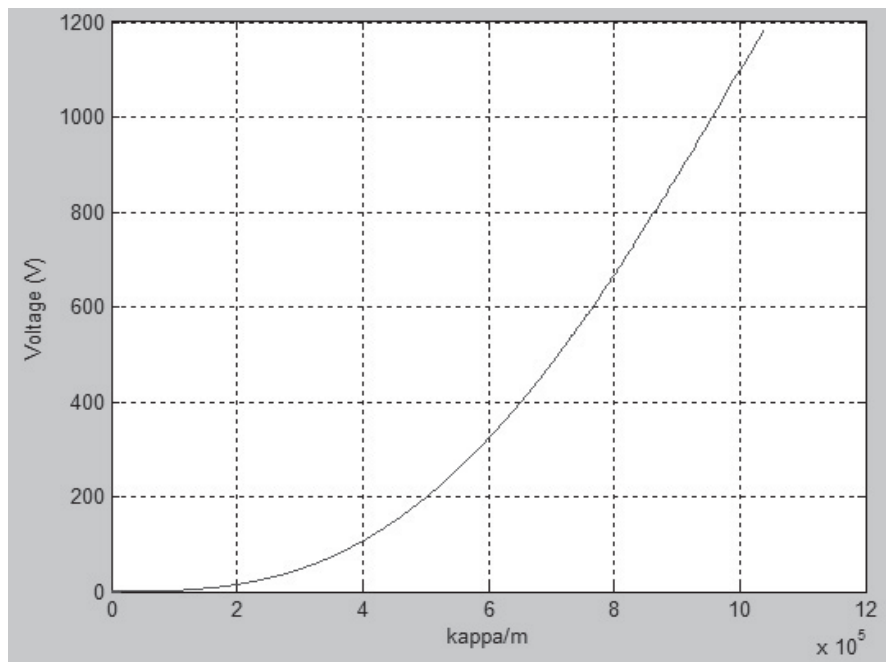


Figure 2. The electric field strength reduces SiO_2 permittivity and it will increase the coupling coefficient

When the dc voltage is increased from 0 to 10V, there is no significant power exchange in both two output ports; this means that the change of coupling parameters is nearly not detected. However, the coupling coefficient is exponentially increased above 10V as shown in Figure 2. The electric field strength between two electrodes tend to polarize the SiO_2 in order its permittivity is reduced. The positive charges of the electrode will interact and affect the polarization in material fibers. This polarization effect causes the refractive index of the SiO_2 changes, the coupling coefficient will then increase. Above 200V the coupling ratio, κ , increases slightly compared <200V. This occurs when the electric field strength is enough to decrease the refractive index, κ is not very significant to change and the power can propagate along the fiber. However when the electric field is very high corresponding to the voltage, the κ is kept to change slightly to the molecular level limit of permittivity SiO_2 .

By measuring the output power and calculating the coupling ratio at the output ports, the coupling ratio as function of dc voltage is shown in Figure 3. It can be seen that the experimental results follows the modeling results with a good agreement. The coupling ratio increases from 0.48-0.53. The small increasing of coupling ratio is caused by the separation of electrodes. In this experiment, the distance between two electrodes is 2.5 mm.

The comparison can be described as follows. In experiment the voltage cannot change the coupling ratio earlier, but when the voltage increases about 350V, the coupling ratio goes up slightly even nearly linear until 250V. This occurs due to the voltage keeps to maintain energy stored in the fibers while it breakdowns. However, when the voltage >450V, the coupling ratio change is very small where if the voltage applies until 1000V, with 500V range, the coupling ratio change is about 0.52-0.53 by factor 10^{-2} . This shows the coupling ratio is no longer effective by voltage. The coupling ratio cannot be rapidly changed beyond 50:50 (for example from 40:60 to 60:40). Since the coupling ratio has two fibers, the fiber splitting the power to another fiber remains to propagate until the range of 50:50. With a theoretical model, the power is not maintained in the fiber while the voltage is imposed along the coupling ratio increases. In theoretical model the voltage is not continuous and no power stored in the fiber then the coupling ratio can increase exponentially.

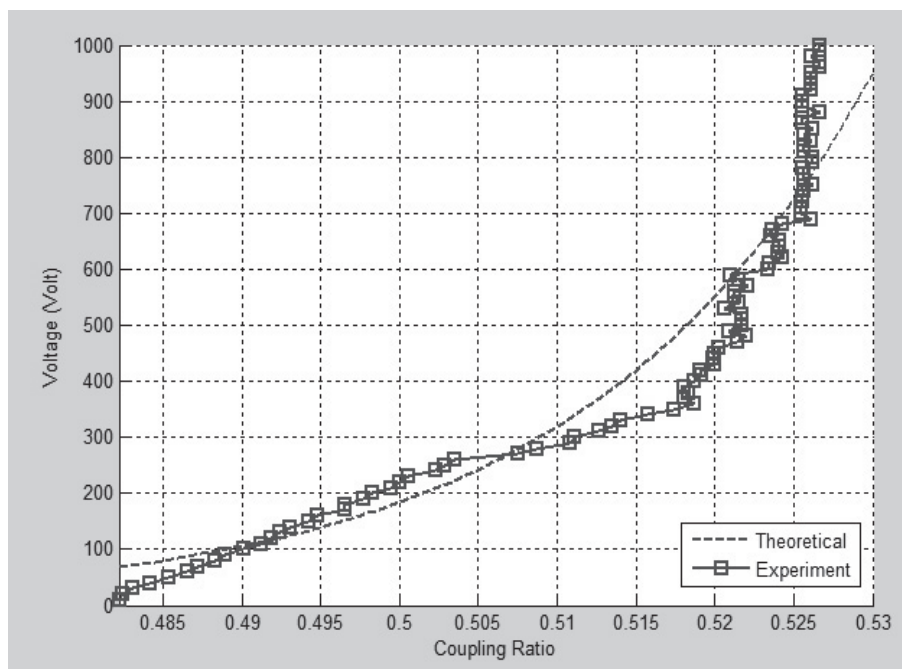


Figure 3. Breakdown voltage at coupling region of 1X2 SMF-28e®

By using breakdown voltage effect to change the coupling ratio theoretically and experimentally, the fiber coupler with tunable coupling ratio will be possible to fabricate optical switch and filter. Figure 3 depicts that the voltage applied is still reasonable to breakdown optical fiber of coupling ratio.

5. CONCLUSION

Applying tunable dc-voltage to the fusion fiber coupler changes the coupling coefficient due to change the permittivity of Silicon dioxide through the refractive index. The experimental results successfully shows the good agreement with the theoretical calculation which purposed by Pockel's model. Both methods describe the coupling coefficient between the fibers exponentially increases by increasing the voltage from 10 to 1000 volt applied to the coupling region mainly in coupling length, and the coupling increases from 0.48 to 0.53.

6. ACKNOWLEDGEMENT

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